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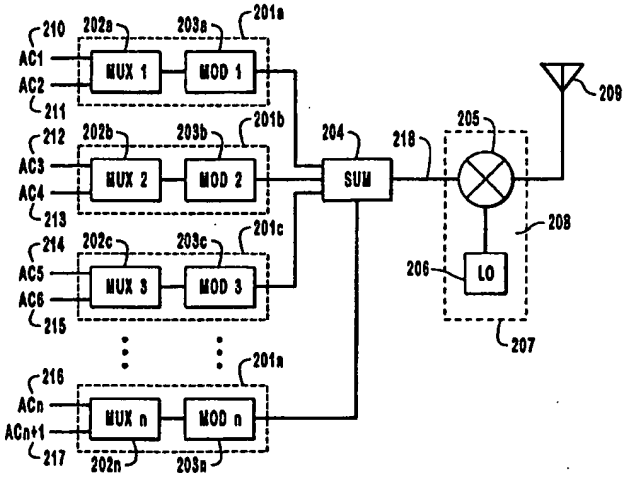

(57) Abstract

A multi-channel wireless speaker system using multiplexed channel combining and frequency diversity is described. The invention is directly applicable to the communication of audio signals between audio signal generators, such as home theater systems, stereo amplifiers, radio receivers, and other similar audio systems. This invention is adapted to provide multiple audio signals (211–217) on a single communication channel. It is specifically adapted to be used with RF wireless (207) and/or AC power line communication channels. This invention avoids the requirement for dedicated wiring connecting the audio signal source and the audio speakers. Moreover, this invention permits a large number of audio signals (211–217) to be separately modulated (201a–201n) and summed (204) on a single composite signal as well as a receiver able to demodulate and demux the composite into the many audio signals which are capable of connection to speakers.

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MULTI-CHANNEL WIRELESS SPEAKER SYSTEM USING MULITPLEXED CHANNEL COMBINING AND FREQUENCY DIVERSITY

Background of the Invention

Field of the Invention. This invention relates to methods and systems for the communication of multiple channel audio signals to audio speakers. More specifically, the invention relates to multi-channel wireless speakers systems which preferably uses power line carrier technology, or alternatively uses a wireless radio frequency (RF) to communicate between an audio transmitter and one or more audio speakers.

Description of Related Art. A variety of multiple channel speaker systems are well known in the art. Generally, these prior systems require that dedicated wired communication between the transmitter and the individual speaker systems be provided. RF wireless speakers have previously been disclosed. however, such speaker systems typically require a dedicated RF frequency or channel for each speaker channel. This invention makes use of multiplexed channel combining and frequency diversity to communicate between an audio transmitter and one or more audio speakers. Typically, and in the preferred embodiment of this invention the communication between the transmitter and the one or more speakers is accomplished over an AC power line. Alternatively, the same multiplexed channel combining and frequency diversity technique of this invention can be used in an RF transmission

system. Audio systems that avoid the requirement of dedicated wires between the transmitter and the speakers are often preferred, especially where the user wishes to avoid the substantial expense and inflexibility of adding through the wall wiring or wishes to avoid unsightly visible and limited wires.

The reader is referred to the following U.S. patent documents for general background material. Each of these patents is hereby incorporated by reference in its entirety for the material contained therein.

U.S. Patent No. 3,590,382 describes a portable wireless stereo sound transmitter and system including one transmitter adapted for connection to one sound source for transmitting sound by wave energy at one high frequency channel to first remote receiving station and another transmitter adapted for connection to another sound source for simultaneously transmitting sound from another sound source for simultaneously transmitting sound from another sound source by wave energy at another high frequency to second remote receiving station.

U.S. Patent No. 3,927,316 describes an infra-red wireless speaker system utilizing an infra-red wide band FM transmitter and receiver.

U.S. Patent No. 4,538,136 describes a power line transmission system which generates a narrow band multi-frequency shift keyed signal having a first and a second predetermined frequency.

U.S. Patent No. 4,597,100 describes a speaker system that includes crossover networks connected to a low output impedance amplifier through RF chokes.

U.S. Patent No. 4,727,600 describes an infrared data repeater adapted for providing communication of infrared signals across an infrared transmission barrier.

U.S. Patent No. 4,837,825 describes a multi-channel stereophonic system in which different audio signals are produced and caused to converge upon the ear of the listener at selectively spaced time intervals so as to enhance the realism of the sound impressed upon the listener.

U.S. Patent No. 4,980,665 describes a repeater for receiving data transmitted via a first transmission medium, transmitting that data over AC power lines to a remote location and re-transmitting that data from the remote location via a second transmission medium.

U.S. Patent No. 5,007,707 describes an array of sound transducers where sound producing groups made up of one or more of the sound transducers may be separately driven so as to spatially reproduce a live performance.

U.S. Patent No. 5,173,942 describes an audio system that includes a speaker unit having an opening in its front surface supporting a speaker and a diffuser with a reflecting surface detachably attached to the speaker unit. A multi-channel amplifier for driving the speaker is also disclosed.

U.S. Patent No. 5,222,145 describes a dual-chamber multi-channel speaker for an audio system, which has four stereo surround sound channels.

U.S. Patent No. 5,233,664 describes a speaker system that includes a common input terminal for receiving an audio signal to be acoustically radiated; several speaker units; several digital filters connected between the common input terminal and the speaker units, and a filter coefficient for each of the digital filters.

U.S. Patent No. 5,302,914 describes a method and apparatus for controlling a linear amplifier processing a plurality of carrier signals of a multi channel carrier

system that alters the phases of one or more sources of the multi-channel signals in response to a detected peak envelope power or of a peak to average power ratio at regular scheduled intervals.

U.S. Patent No. 5,497,425 describes a passive multi channel surround sound simulation device that has a pair of input jacks for receiving a two channel stereophonic signal having a speaker level.

U.S. Patent No. 5,581,617 describes a system, which transmits either analog or digital data signals over the air.

U.S. Patent No. 5,673,323 describes an analog spread spectrum wireless speaker system for use in consumer audio applications for providing reliable and high fidelity stereo sound.

U.S. Patent No. 5,708,719 describes an apparatus for realistically reproducing sound, particularly for sound based on a stereophonic signal having dialog and effects and associated with an accompanying video image.

U.S. Patent No. 5,751,821 describes a high-quality audio frequency loudspeaker system utilizing an array of tweeters placed in vertical alignment along an axis.

U.S. Patent No. 5,768,394 describes a surround audio signal reproducing apparatus for reproducing a multi-channel audio signal to generate a surround sound effect.

U.S. Patent No. 5,799,042 describes a wireless digital communication system that applies an antenna diversity scheme to combat fading in a received signal as received by a receiver in the system.

Summary of the Invention

It is desirable to provide a system for communicating between an audio transmitter and one or more audio speakers. It is particularly desirable to provide such a system where no dedicated wires are required to effect the communication channel and moreover, it is desirable to make use of a multiplexed channel combining and frequency diversity scheme. Many of the advantages of this invention are discussed in further detail in the previously cited patent literature.

Accordingly, it is the primary object of this invention to provide a multi-channel audio system for communicating between an audio transmitter and one or more audio speakers that does not require dedicated wiring.

Another object of this invention is to provide a multi-channel audio system that uses multiplexed channel combining and frequency diversity.

Another object of this invention is to provide a multi-channel audio system that is adapted specifically to the requirements of AC power line and RF communication channels.

A further object of this invention is to provide a multi-channel audio system that is adapted specifically to the requirements of home theater systems.

A still further object of this invention is to provide a multi-channel audio system that is adapted specifically to the requirements of surround sound systems.

Additional objects, advantages, and other novel features of this invention will be set forth in part in the description that follows and in part will become apparent to those skilled in the art upon examination of the following or may be learned with the practice of the invention. The objects and advantages of this invention may be

realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims. Still other objects of the present invention will become readily apparent to those skilled in the art from the following description wherein there is shown and described the preferred embodiment of this invention, simply by way of illustration of one of the modes best suited to carry out this invention. As it will be realized, this invention is capable of other different embodiments, and its several details, and specific electronic circuits, are capable of modification in various aspects without departing from the invention. Accordingly, the drawings and descriptions should be regarded as illustrative in nature and not as restrictive.

To achieve the foregoing and other objectives, and in accordance with the purposes of the present invention, an audio signal generator is provided to send signals to the multi-channel wireless speaker transmitter, which in turn sends multiple channel signals over the A/C power lines or, alternatively, over the air by RF waves. One or more multi-channel speaker receivers is provided to demodulate and de-multiplex the signals, and to send the signals to one or more audio speakers. For the purposes of this disclosure the combination of speaker receiver and attached speakers is referred to as a speaker connection module. Frequency diversity is used to separate the speaker connection modules and multiplexing techniques are used to separate the speakers within each speaker connection module.

Brief Description of the Drawings

The accompanying drawings incorporated in and forming a part of the specification, illustrate a preferred embodiment of the present invention. Some,

although not all, alternative embodiments are described in the following description. In the drawings:

Figure 1 is a top level system block diagram showing the major sections of the invention.

Figure 2 is a block diagram providing additional detail on the multi-channel wireless speaker transmitter of the preferred embodiment of the invention.

Figure 3 is a block diagram providing additional detail on the multi-channel wireless speaker receiver of the preferred embodiment of the invention.

Figure 4 is a detailed block diagram of the preferred internal components of the multiplexer of the preferred wireless transmitter of the invention.

Figure 5 is a detailed block diagram of a first preferred sum and difference demux of the preferred wireless speaker receiver.

Figure 6 is a detailed block diagram of a second preferred direct channel demux of the preferred wireless speaker receiver.

Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings.

Detailed Description of the Invention

Figure 1 shows the top level system block diagram of the major sections of the invention. In particular, an audio signal generator 101 is provided as the source of the audio signals. The audio signal generator 101 communicates the audio signals to the multi-channel wireless speaker transmitter 102. The multi-channel wireless speaker transmitter 102 generates and sends multiple channel signals to one or more wireless receiver/speakers modules 103a-n. The wireless receiver/speakers modules 103a-n

preferably include three component parts: the multi-channel receiver 104a-n and one or more speakers 105-n, 106a-n. The preferred signal channel 107 between the wireless speaker transmitter 102 and the multi-channel wireless speaker receivers 104a-n is the AC power line. Typically, AC power lines are preexistent in the buildings or facilities and are available for easy access to audio equipment, including transmitters, receivers and speakers. Using AC power lines permits a user to install an audio system without requiring that the user use inconvenient and often unsightly single purpose wires between the transmitter/receiver and the speakers of an audio system. Alternative, communication channels which could be substituted without departing from the concept of this invention include RF wireless transmitters/receivers. Once received by the multi-channel wireless speaker receivers 104a-n, the signals are demodulated and de-multiplexed and send to the respective speakers 105a-n,106a-n, or other audio listening products, such as headphones, ear phones or the like. While, figure 1 shows each multi-channel wireless speaker receiver 104a-n being connected to two speakers 105a-n, 106a-n, alternative numbers of speakers, such as mono audio (one speaker), quadraphonic (four speakers), or surround sound (four to six speakers) can be used without departing from the concept of this invention. Similarly, this invention contemplates a wide variety in the number of speaker/receiver modules 103a-n. Each speaker/receiver module 103a-n operates on a different carrier frequency. This invention uses frequency diversity to separate the signals for each speaker/receiver module 103a-n and uses multiplexing techniques to separate the signals for the speakers 105a-n, 106a-n within each speaker/receiver module 103a-n.

Figure 2 shows a block diagram of the multi-channel wireless speaker transmitter 102 of the preferred embodiment of the invention. In this preferred embodiment, two channels, audio channel one 210 and audio channel two 211 are combined in a multiplexer 202a and then sent to a modulator 203a which puts the audio channels on a carrier frequency for transmission. This system is capable of transmitting more than two channels of audio information by using multiple multiplexer modules 201a,b,c,n. Each multiplexer module combines two audio channels, a channel one 210, 212, 214, 216, and a channel two 211, 213, 215, 217, using a multiplexer 202a-n, and a modulator 203a-n. The embodiment of the speaker transmitter 102 shown in figure 2 shows four multiplexer modules 201a-n. Nevertheless, the invention is not limited to simply four modules 201a-n. Alternative embodiments of this invention may use a wide variety of number of multiplexer modules as necessary to accommodate the number of audio channels. The multiple multiplexer modules 201a-n are combined into one channel using a summer 204. The composite signal 218 can be used preferably directly for power line transmission or, alternatively, if a higher carrier frequency is employed, as is typical for RF data links 209, 301 (see figure 3), then a mixer 205 and a local oscillator (LO) 206 is used in an up-converter 207 to up-convert the composite signal to a higher frequency. The composite modulated frequency signal is then transmitted using the AC power lines or RF wireless data links.

Figure 3 shows a block diagram that provides additional detail on the multi-channel wireless speaker receiver 104 of the preferred embodiment of the invention. The preferred multi-channel wireless speaker receiver 104 receives the composite

modulated frequency signals from the multi-channel wireless speaker transmitter 102 by means of the AC power line carrier data link 107 or alternatively by the RF wireless data link 209, 301. If up-conversion is used in the transmitter 102, as described above, then the optional down-converter 308 mixer 302 and local oscillator (LO) 303 are provided to down-convert the received signal. The received signal is then passed through band pass filters (BPF) 304a-n, adapted to provide multiple channels by using frequency diversity. Each of these filtered signals is passed through a demodulator 305a-n, where the audio signal is retrieved off the carrier frequency. The demodulated signal is then passed through a de-multiplexer 306a-n where the two multiplexed audio signals 309, 310, 311, 312, 313, 314, 315, 316 are derived. In the multi-channel scheme, several detector modules 307a,b,c,n are paralleled to give any number of desired audio channels.

Figure 4 is a detailed block diagram of the preferred internal components of the multiplexer 202 of the preferred wireless transmitter 102 of the invention. The multiplexer 202 receives the two audio channels AC1 210, AC2 211 and provides them to combiners 401, 402 that add the audio channels in one path 409 and subtract the channels in the other path 410. One of the output channels, in this preferred case the difference channel 410, is mixed with a local oscillator frequency, generated by local oscillator 404, by a mixer 403. Thus, the difference channel 410 is up-converted while the sum channel 409 is not. The up-converted channel is then filtered by a low pass filter 405 in preparation for summing in summer 408. The same local oscillator 404 output is divided by 2 in frequency in divider 406 and then put through a time delay 407 or phase shifter and then is summed 408 with the output of the low pass

filter 405 from the difference channel 410 and the output of the combiner 402 , the sum channel 409. The output 411 of the summer 408 is the presented to the modulator 203.

Two different and alternative demultiplers 306 can be used in this invention. A first preferred demultiplexer is a sum and difference demux as shown in Figure 5. The second preferred demultipler, shown in Figure 6, employs a technique which uses the multiplexed signal itself for direct detection.

The first preferred demultiplexer embodiment, as shown in Figure 5, uses the sum and difference technique. The summer output signal 411, composed of three types of signals, namely (1) a pilot tone or reference signal; (2) the difference signal; and (3) the sum signal. The pilot tone is provided to give coherent detection. A band pass filter, BFP2, 501 filters out the other two signals present. The output 513 of BFP2 501 is fed into a carrier recovery loop (CRL) 502. The carrier recovery loop 502 uses a phase comparator 503 to compare the phase of the incoming signal 513 with a reference signal 514 and produces an error signal 515. The error signal 515 is fed into a loop filter 506, the output of which 516 is fed into the voltage controlled oscillator (VCO) 505, phase locking the VCO 505 to the input frequency and providing a coherent reference 517 for the input of the mixer 508. The reference signal 514 is generated by divide by 2 circuit 504. The divide by 2 circuit receives as its input 518 an output from the VCO 505, thereby completing a feedback loop.

The difference signal is passed by the band pass filter 1, BPF1, 507 and is the other input 519 to the mixer 508. The output 520 of the mixer 508 is fed into a low pass filter, LPF1, 509, where spurious signals are reduced, the output of which 521 is

a coherent baseband difference channel. The sum signal component of the composite signal 411 is passed through a low pass filter, LPF2, 510 to reduce out-of-band signals. The filtered sum 522 and difference 521 channels are combined in the combiners 511, 512 to produce the separate audio channels ASC1 309 and ASC2 310.

Figure 6 shows the detailed block diagram of a second preferred demultiplexer, which can be used as the channel demux 306 of the preferred wireless speaker receiver 104 of this invention. This demulitiplexer embodiment uses a direct approach for detection. The composite signal 411 received from the demodulator 305 is split into two paths, 611, 612. The first path 611 is filtered by a band pass filter, BPF1, 601, the output 613 of which is multiplexed by multiplexer 608 between audio signal channel 1, ASC1 309, and audio signal channel 2, ASC2, 310. The second path 612 contains the pilot tone or reference frequency of the composite signal 411. The pilot tone 612 is filtered by band pass filter, BPF2, 602 . The output 614 of BPF2 602 is fed into a carrier recovery loop (CRL) 603 to recover the carrier signal for coherent detection of the multiplexed signal. The CRL 603 uses a phase comparator 604 to compare the phase of the incoming tone 614 with a reference signal 615 and produces an error voltage 616. The reference signal 615 is generated by a voltage controlled oscillator (VCO) 606, whose output 617 is divided in frequency by a divide by 2, 605. The error voltage 616 is fed into a loop filter 607, the output 618 of which locks the VCO 606 with the input frequency and provide a coherent reference 619 for the input to the demultiplexing switch 608. The outputs 620, 621 of the demultiplexing switch 608 are fed into low pass filters, 609, 610. The outputs of the low pass filters 609,

610 produce the two audio channels, ASC1 309 and ASC2 310, which are adapted to be received by the speakers 105, 106.

The foregoing description is of preferred embodiments of the invention and has been presented for the purposes of illustration and as a description of the best mode of the invention currently known to the inventors. It is not intended to be exhaustive or to limit the invention to the precise form, connections, or choice of components disclosed. Obvious modifications or variations are possible and foreseeable in light of the above teachings. This embodiment of the invention was chosen and described to provide the best illustration of the principles of the invention and its practical application to thereby enable on of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when they are interpreted in accordance with the breadth to which they are fairly, legally and equitably entitled.

Claims

We claim:

1. A multi-channel wireless communication system for transmitting multiple electronic audio signals and for receiving such multiple audio signals to audio speakers, comprising:

   (A) an audio signal generator;

   (B) a wireless speaker transmitter electrically connected to said audio signal generator;

   (C) a wireless speaker receiver; and

   (D) a communication link connecting said wireless speaker transmitter to said wireless speaker receiver.

2. A multi-channel wireless communication system, as recited in claim 1, wherein said audio signal generator is selected from the group consisting of a radio receiver, a home theater audio amplifier, a stereo amplifier, and a surround sound amplifier.

3. A multi-channel wireless communication system as recited in claim 1 wherein said wireless speaker transmitter further comprises:

   (1) a first multiplexer module, having as inputs a plurality of audio signals from said audio signal generator and an output; and

   (2) a summer electrically connected to said output of said multiplexer module and generating a composite audio signal.

4. A multi-channel wireless communication system as recited in claim 1 wherein said wireless speaker transmitter further comprises a second multiplexer

module, having as inputs a plurality of audio signals and an output electrically connected into said summer.

5. A multi-channel wireless communication system as recited in claim 1 wherein said wireless speaker transmitter further comprises an up-converter receiving said composite signal from said summer.

6. A multi-channel wireless communication system as recited in claim 1 wherein said communication link further comprises an RF data link.

7. A multi-channel wireless communication system as recited in claim 1 wherein said communication link further comprises an AC power line communication channel.

8. A multi-channel wireless communication system as recited in claim 1 wherein said wireless speaker receiver further comprises:

(1) a filter, having an input and an output;

(2) a demodulator, having an input and an output, wherein said input is electrically connected to said output of said filter;

(3) a demultiplexer, having an input and an output, wherein said input is electrically connected to said output of said demodulator.

9. A multi-channel wireless communication system as recited in claim 1 wherein said wireless speaker receiver further comprises a down-converter receiving a composite signal from said wireless speaker transmitter.

10. A multi-channel wireless communication system as recited in claim 8 wherein said demodulator further comprises:

(a) a filter receiving audio signals;

(b) a carrier recovery loop circuit;

(c) a mixer, electrically connected to said filter and to said carrier recovery loop circuit;

(d) a low pass filter electrically connected to said mixer; and

(e) a combiner electrically connected to said low pass filter.

11. A multi-channel wireless communication system as recited in claim 8 wherein said demodulator further comprises:

(a) a filter receiving audio signals;

(b) a carrier recovery loop circuit;

(c) a multiplexer, electrically connected to said filter and to said carrier recovery loop circuit;

(d) a low pass filter electrically connected to said mixer; and

(e) a combiner electrically connected to said low pass filter.

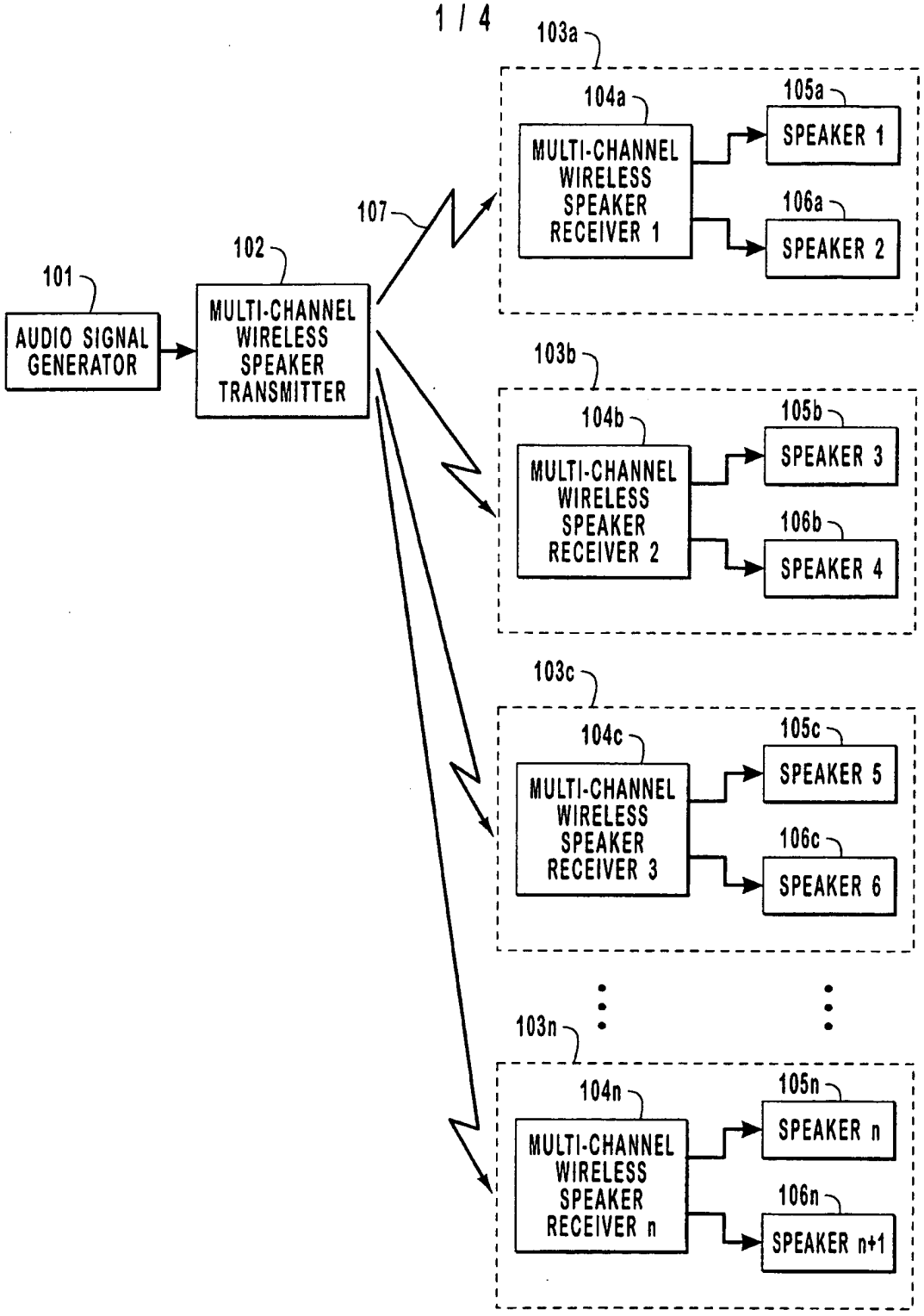
12. A multi-channel wireless communication system as recited in claim 3 wherein said first multiplexer further comprises:

(a) a first combiner and a second combiner;

(b) a mixer, electrically connected to said first combiner;

(c) a filter electrically connected to said mixer; and

(d) a summer electrically connected to said second combiner and said filter.


101
AUDIO SIGNAL GENERATOR
102
MULTI-CHANNEL WIRELESS SPEAKER TRANSMITTER
107
103a
104a
MULTI-CHANNEL WIRELESS SPEAKER RECEIVER 1
105a
SPEAKER 1
106a
SPEAKER 2
103b
104b
MULTI-CHANNEL WIRELESS SPEAKER RECEIVER 2
105b
SPEAKER 3
106b
SPEAKER 4
103c
104c
MULTI-CHANNEL WIRELESS SPEAKER RECEIVER 3
105c
SPEAKER 5
106c
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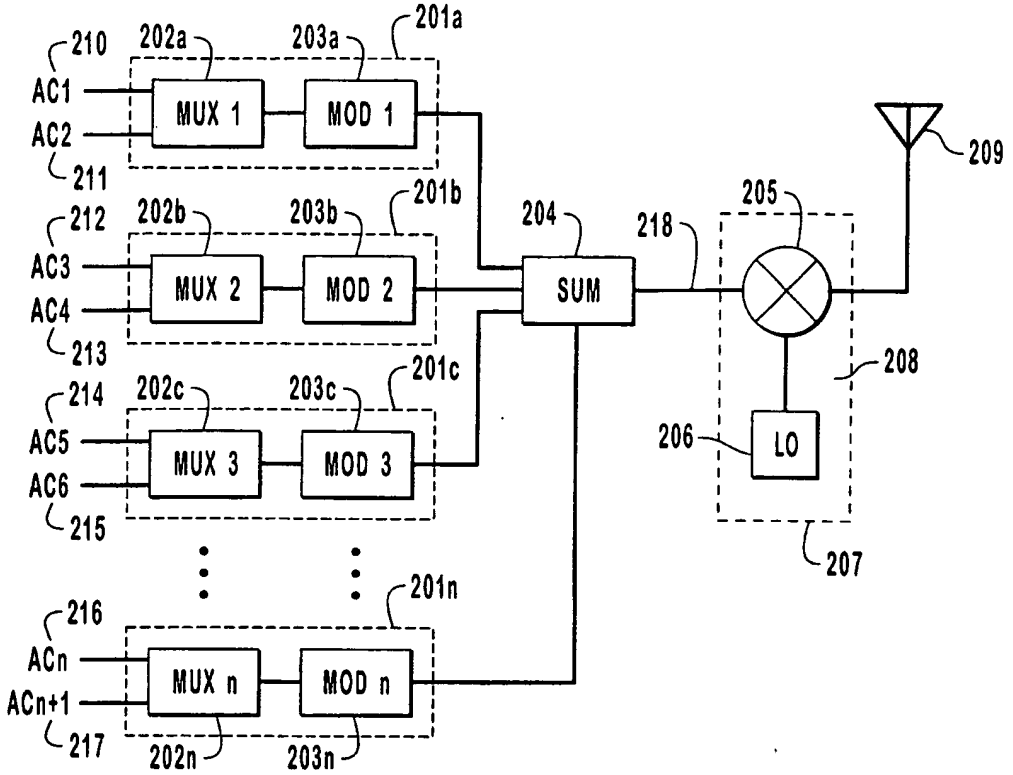
105n
SPEAKER n
106n
SPEAKER n+1

FIG. 1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214
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203c
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AC5
AC6
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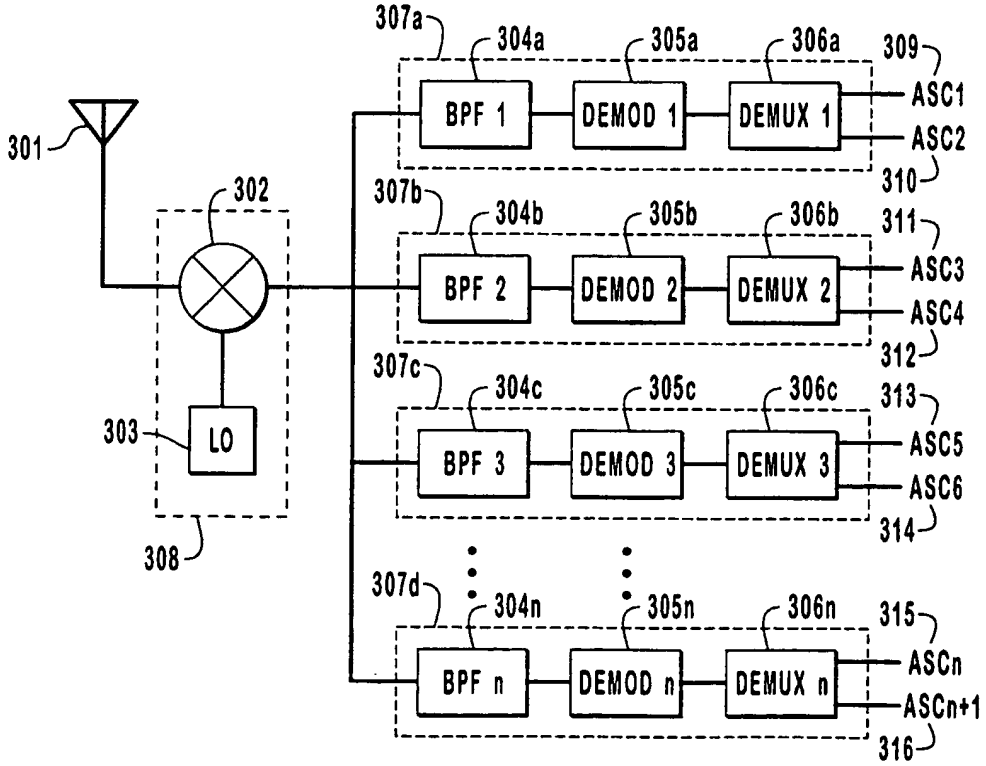
202n
203n

FIG. 2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BPF 3
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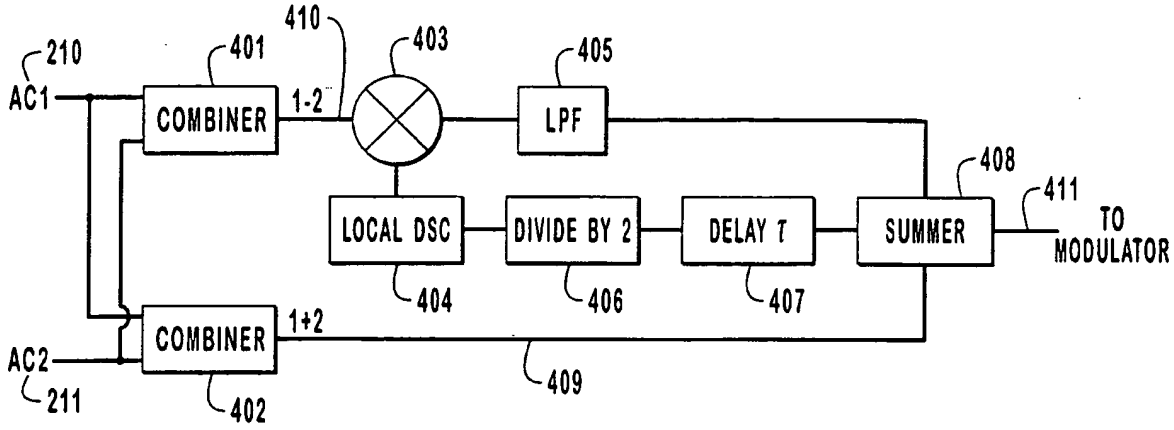
FIG. 3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LPF
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411
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406
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COMBINER
1+2
AC2
211
402
409

FIG. 4

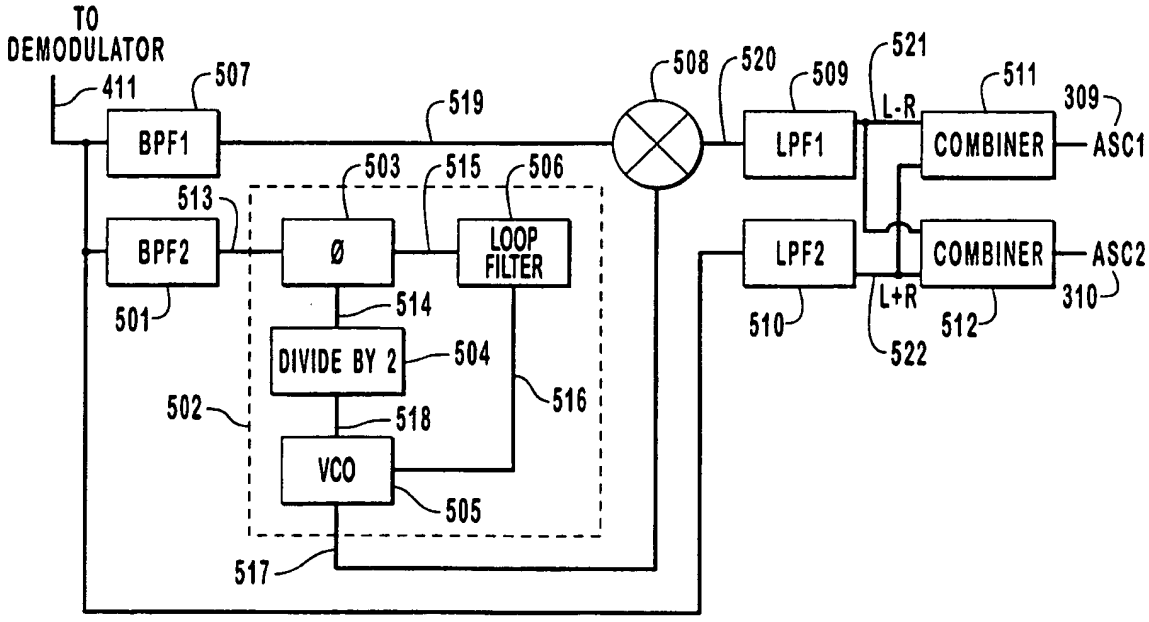
TO DEMODULATOR
411
507
BPF1
519
508
520
509
521
L-R
511
309
LPF1
COMBINER
ASC1
503
515
506
513
BPF2
Ø
LOOP FILTER
LPF2
COMBINER
ASC2
514
501
510
L+R
512
310
522
DIVIDE BY 2
504
502
516
518
VCO
505
517

FIG. 5

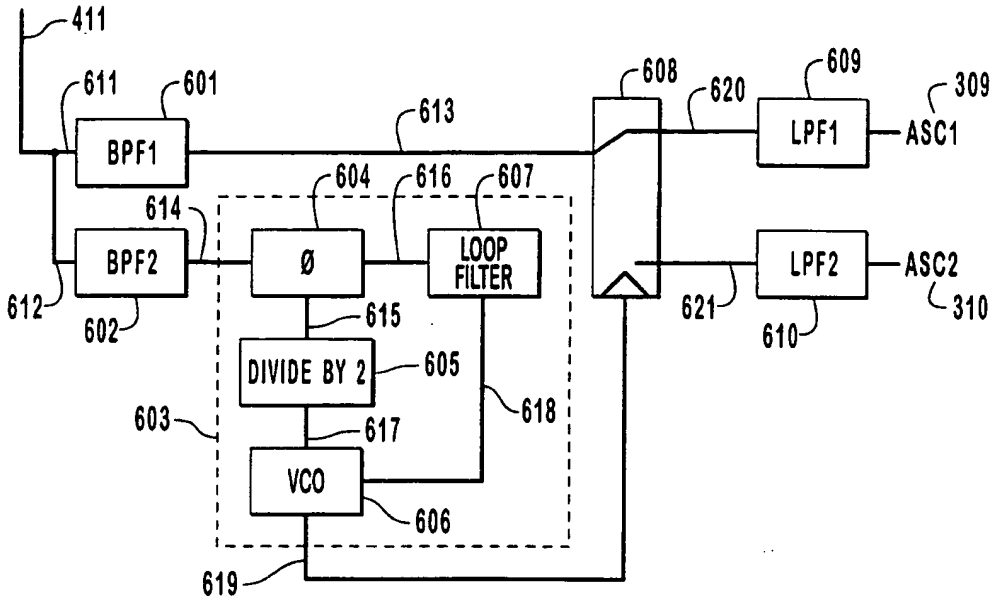
411
611
601
613
608
620
609
309
BPF1
LPF1
ASC1
604
616
607
614
BPF2
Ø
LOOP FILTER
LPF2
ASC2
612
602
615
621
610
310
DIVIDE BY 2
605
618
603
617
VCO
606
619

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/28163

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 3/00; H04H 5/00
US CL :381/81, 2

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 381/79-81, 85, 2,

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,425,101 A (WOO et al) 13 June 1995, figure 1.	1, 2, 5-9
X	US 4,922,483 A (KOBAYASHI) 01 May 1990, figure 2.	1-4, 6-9
Y		10-12
Y	US 5,408,686 A (MANKOVITZ) 18 April 1995, figure 1.	10, 12
Y	US 5,293,633 A (ROBBINS) 08 March 1994, figure 8.	11

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 21 JANUARY 2000	Date of mailing of the international search report 07 FEB 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PING LEE Telephone No. (703)305-3900

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